Massive MIMO Antenna Array Design and Challenges

Dr Yue Gao
Antennas & Electromagnetics Research Group
yue.gao@qmul.ac.uk
http://www.eecs.qmul.ac.uk/~yueg/

Queen Mary
University of London

April 2015

Outline

- Introduction from MIMO to massive MIMO
- The requirements for massive MIMO antenna array
- The design and performance of a single element
- The design and performance of a sub-array
- The design and performance of a Massive MIMO antenna array
- Conclusions & future work

Abstract

Recent advance on Multiple Input and Multiple Output (MIMO) [1] have led the transformation from a point-to-point single user MIMO to multi-user MMO (MU-MIMO). The MU-MIMO refers to a base station (BS) with multiple antennas simultaneously serves a set of single-antenna users, and the multiplexing gain can be shared by all users. With the staggering increase of wireless data traffic, massive MIMO enhancing MU-MIMO benefits has shown over 10 times spectral efficiency increase over a point-to-point MIMO under realistic propagation environment with simpler signal processing algorithms. Massive MIMO is also known as “Large-Scale Antenna Systems”, “Very Large MIMO”, “Hyper MIMO”, “Full-Dimension MIMO” and “ARGOS”), where each BS is equipped with orders of magnitude more antennas, e.g., 100 or more. This has brought a new paradigm for antennas and propagation society to tackle challenges to design over 100 antenna ports at base station with a set of new requirements. This introduction briefly reviews the progress from MIMO to massive MIMO, and addresses the key challenges for massive MIMO antenna array design via an example antenna array design [2].

Keyword: MIMO, MU-MIMO, Massive MIMO, large-scale antenna array

[1]. Y. Gao, X. Chen, Z. Ying and C. G. Parini, “Design and Performance Investigation of a Dual-element PIFA Array at 2.5 GHz for MIMO Terminal,” IEEE Trans. On Antennas and Propagation, Vol. 55, No. 12, pp: 3433 - 3441, Dec. 2007.
[2] R. Ma, Y. Gao, L. Cuthbert and C. G. Parini, "Dual-polarized Turning Torso Antenna Array for Massive MIMO Systems," The 9th European Conference on Antennas and Propagation (EuCAP 2015), Apr. 2015.

A point-to-point MIMO antenna system

- Multiple Input and Multiple Output (MIMO) has been well studied and understood in terms of point-to-point MIMO links as shown in Fig. 1 to achieve:
  1) Enhance radio link reliabilities via diversity [3]
  2) Increase data rate via multiplex [4]
- In a MIMO system in a given frequency band and time slot in a multipath environment, the reliability or capacity can be linearly increase with the number of transmitter and receiver antennas.
- This has brought huge challenges for antenna society to hosting multiple antennas in a size limited mobile terminal as shown in Fig. 2 [1].

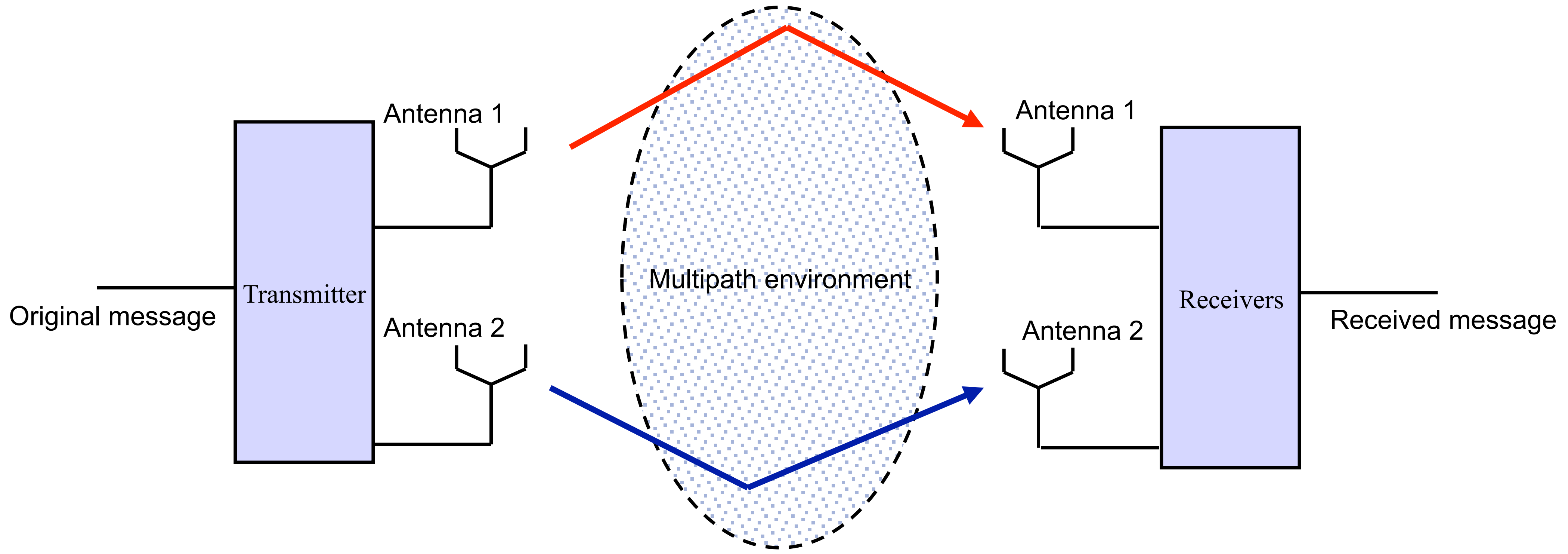

Original message
Transmitter
Antenna 1
Antenna 2
Multipath environment
Antenna 1
Antenna 2
Receivers
Received message

Fig. 1 a point-to-point MIMO antenna system

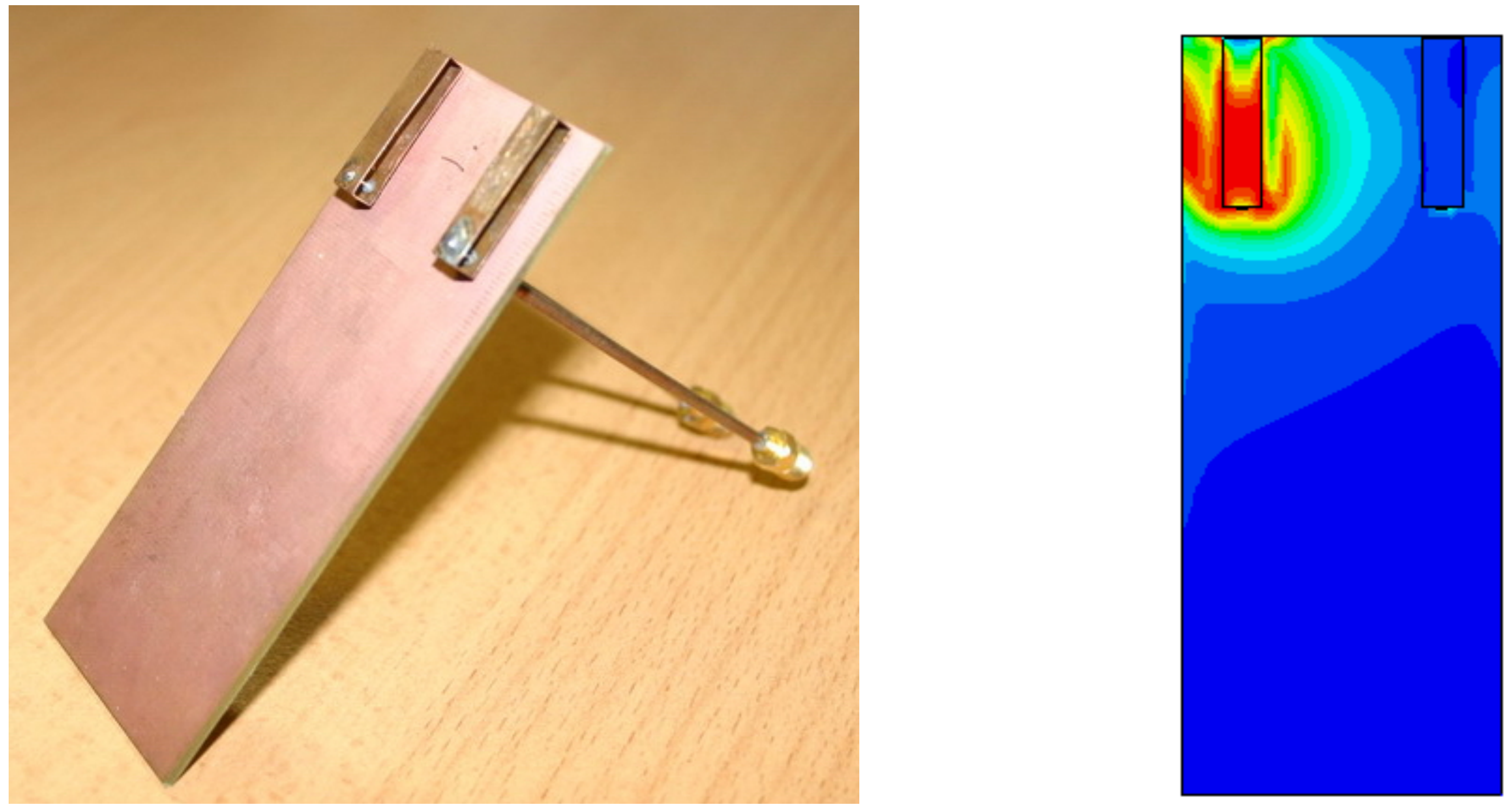


Fig 2. a prototype (left) of the dual-element antenna array and current distribution (right)

[3] J. H. Winters, “On the capacity of radio communication systems with diversity in a Rayleigh fading environment,“ IEEE Journal on Selected Areas in Communications Vol. 5(No. 5): 871–878, 1987.
[4] G. Foschini, “Layered space-time architecture for wireless communi- cation in a fading environment when using multi-element antennas,” Bell Labs Tech. J., vol. 1, no. 2, pp. 41–59, 1996.

A multi-user MIMO (MU-MIMO) system

- Multipath propagation environment for all communication scenarios and multiple antennas at mobile terminal (over 4 antennas) are very nearly impossible to be achieved in practice.
- A multi-user MIMO (MU-MIMO) antenna system refers to a base station (BS) with multiple antennas simultaneously serves a set of single-antenna users and the multiplexing gain can be shared by all users [5].
- This has reduced the challenges to hosting multiple antennas in a size limited mobile terminal and antennas at base station only with 8 ports in LTE-Advanced.

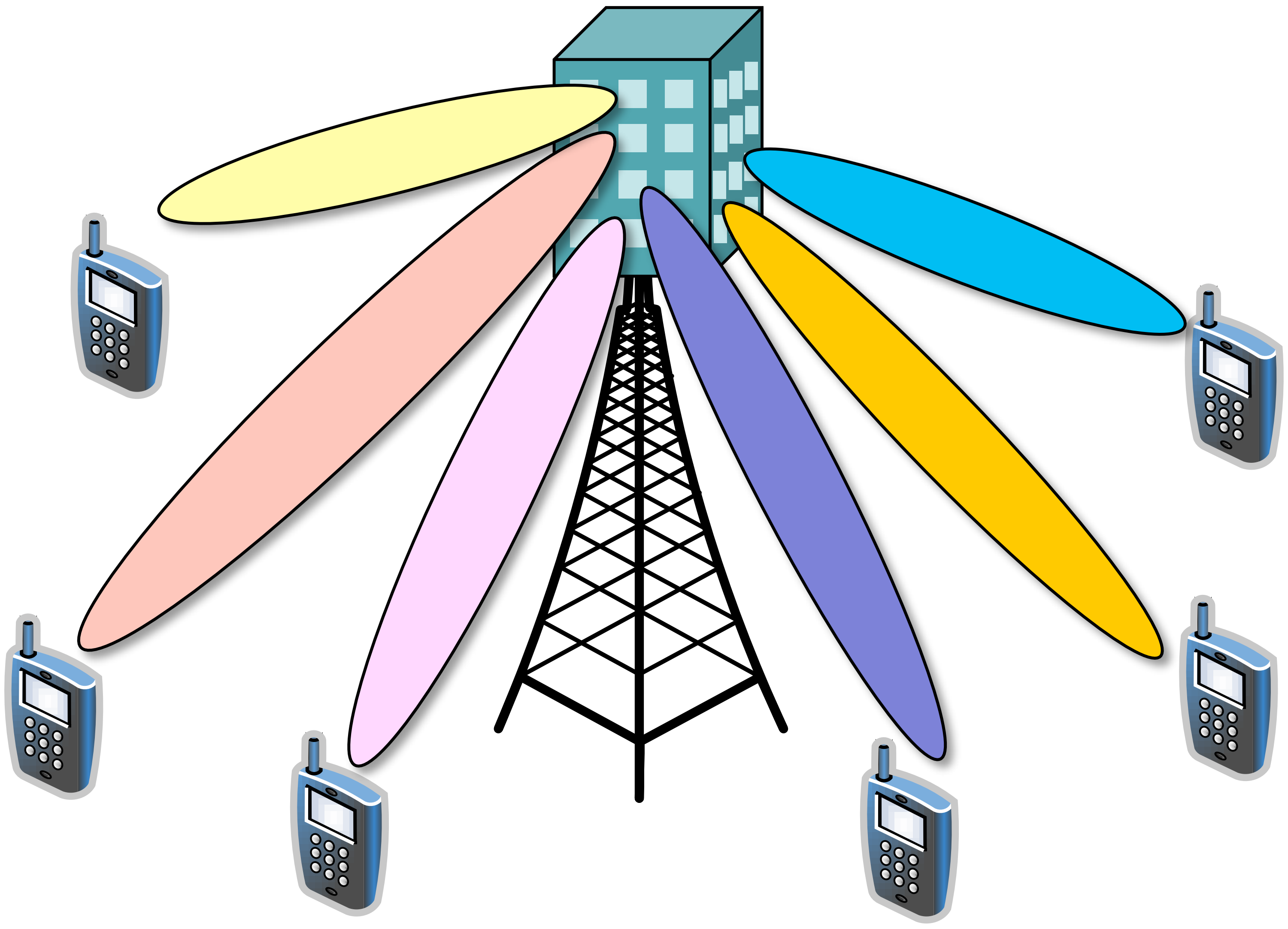


Fig. 3 A multi-user MIMO (MU-MIMO) system which is less sensitive to prorogation environment.

[5] D. Gesbert, M. Kountouris, R. W. Heath, Jr., C. B. Chae, and T. Salzer, "From Single user to Multiuser Communications: Shifting the MIMO paradigm," IEEE Signal Processing Magazine, Vol. 24, No. 5, pp. 36-46, Oct., 2007.

A massive MIMO antenna system

- Extending the benefits of MU-MIMO, Massive MIMO is also known as “Large-Scale Antenna Systems”, “Very Large MIMO”, “Hyper MIMO”, “Full-Dimension MIMO” and “ARGOS”), where each BS is equipped with orders of magnitude more antennas, e.g., 100 or more [6].
- Massive MIMO has shown over 10 times spectral efficiency increase over a point-to-point MIMO under realistic propagation environment with simpler signal processing algorithms [7][8].
- Massive MIMO has brought significant challenges to AP society as we have not experienced to designed over 100 antenna ports at base stations in a compact size.

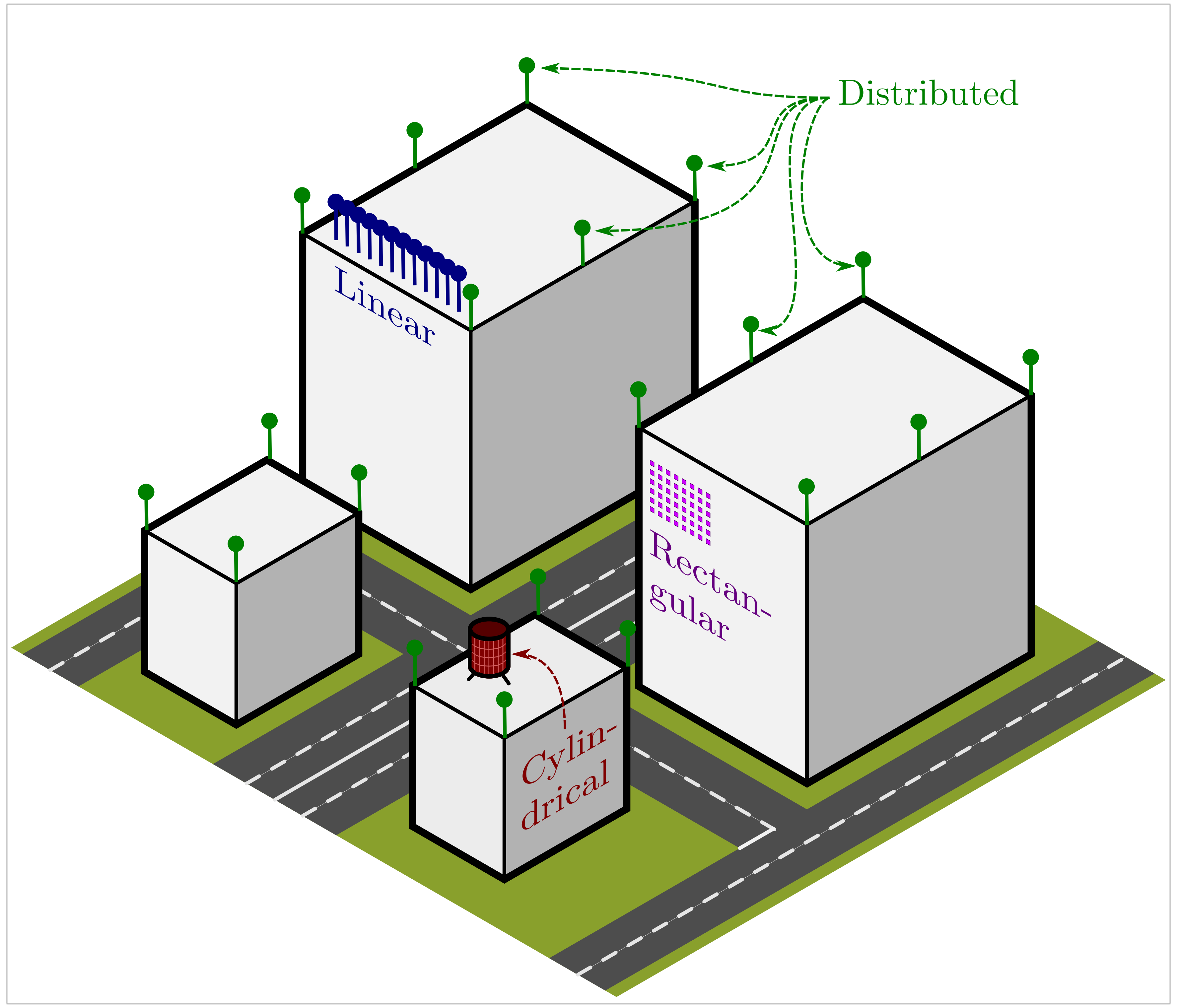


Fig. 3 some possible antenna configurations and deployment scenarios for a massive MIMO base station [8].

[6] T. L. Marzetta, “Noncooperative Cellular Wireless with Unlimited Numbers of Base Station Antennas,” IEEE Trans. Wireless Commun., vol. 9, no. 11, pp. 3590–3600, Nov. 2010.
[7] F. Rusek, D. Persson, B. K. Lau, E. G. Larsson, T. L. Marzetta, O. Edfors, and F. Tufvesson, “Scaling Up MIMO: Opportunities and challenges with very large arrays,” IEEE Signal Processing Mag., vol. 30, no. 1, pp. 40–60, Jan. 2013.
[8] E. G. Larsson, F. Tufvesson, O. Edfors, and T. L. Marzetta, “Massive MIMO for Next Generation Wireless Systems,” IEEE Commun. Mag., vol. 52, no. 2, pp. 186–195, Feb. 2014.

Challenges for Massive MIMO antennas

- Compact and low profile
- Low mutual coupling
- High gain to reduce cost of RF chains
- Flexibility: Centralised/distributed
- Configuration and orientations
- Multi-modes operations
- Multiple frequency bands
- Correlation coefficient
- Channel characterization

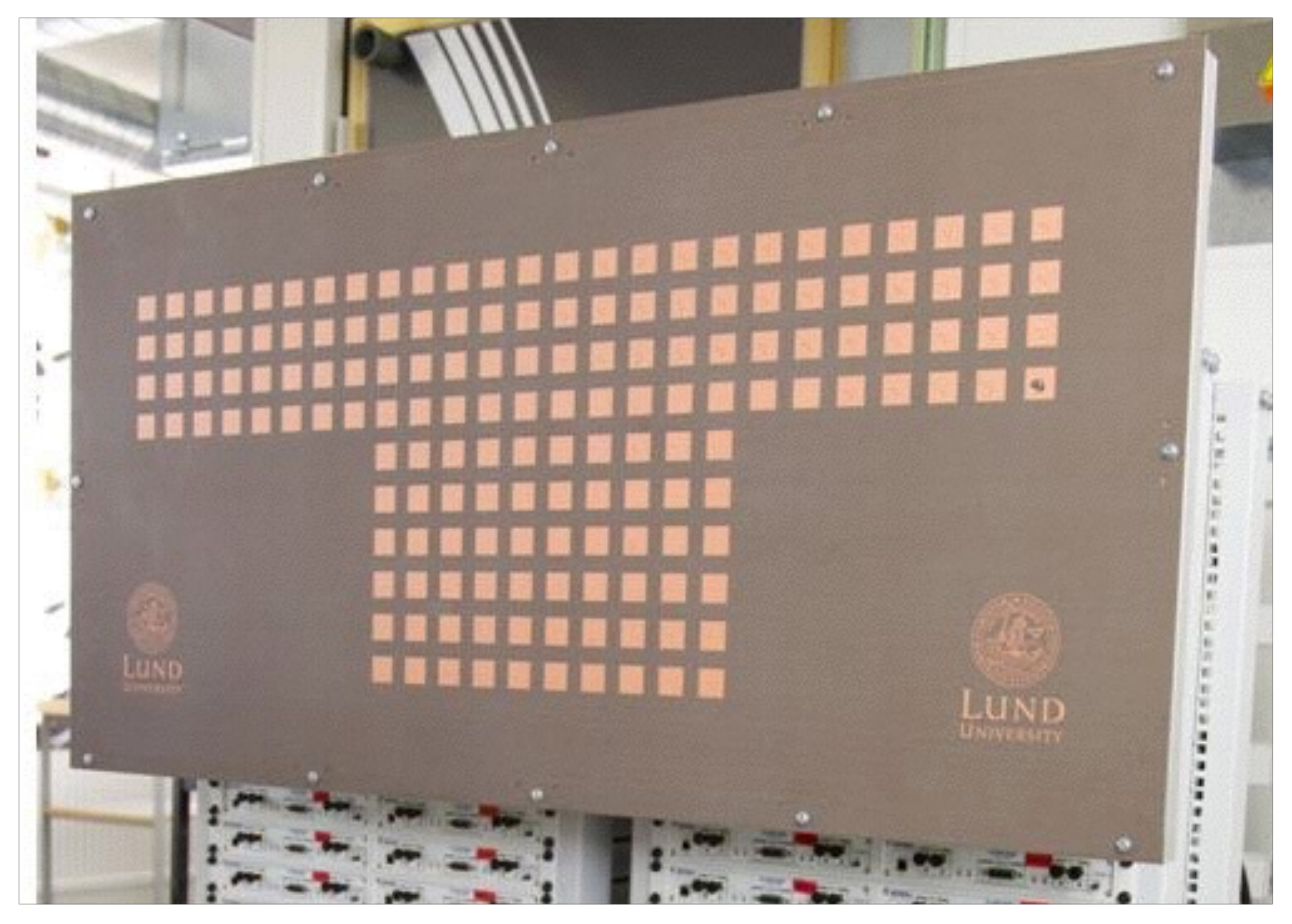


Fig. 4 the massive MIMO antenna array made by Lund University
http://www.ni.com/white-paper/52382/en/

The design of a single element

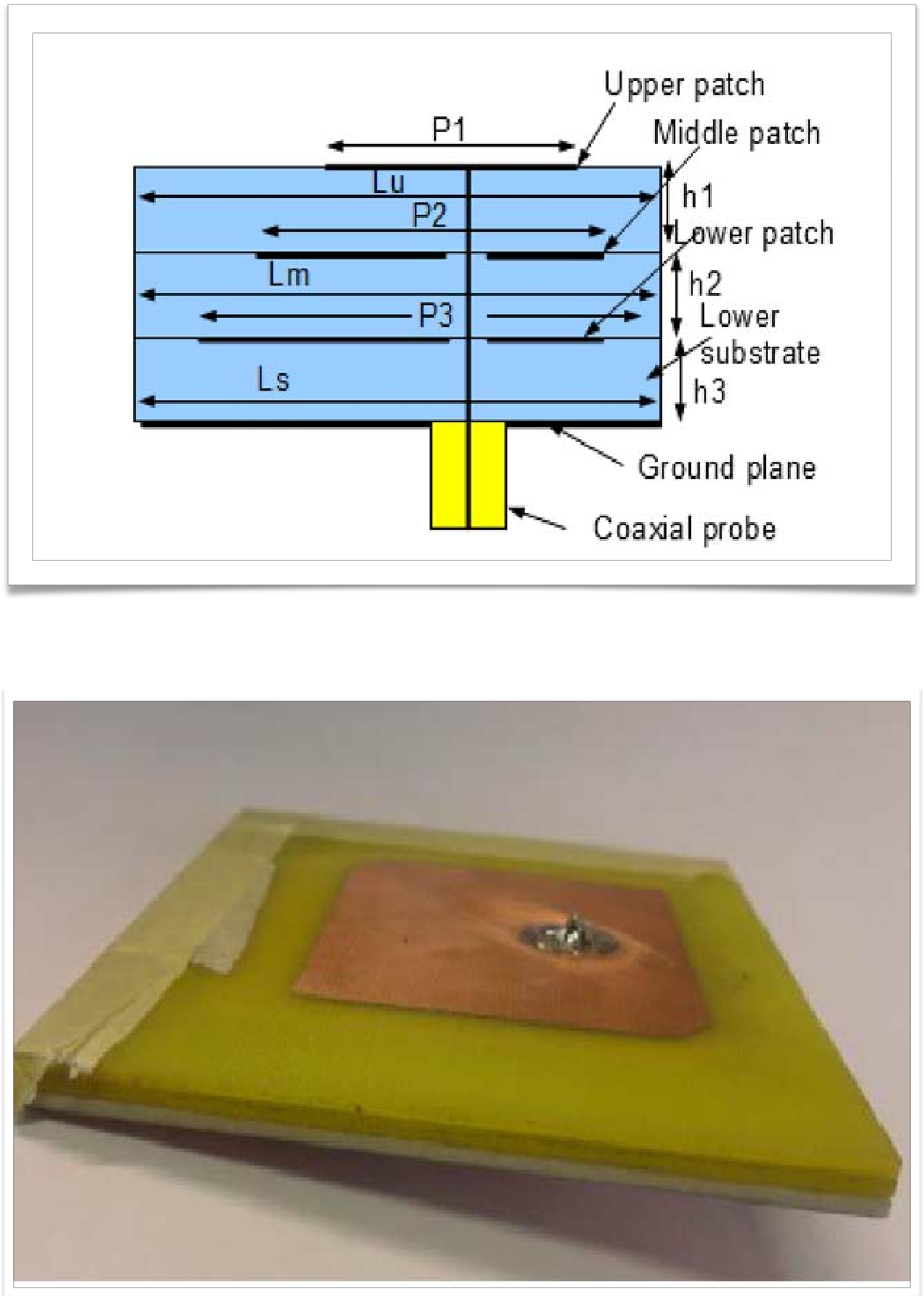

Upper patch
P1
Middle patch
Lu
h1
P2
Lower patch
Lm
h2
P3
Lower substrate
Ls
h3
Ground plane
Coaxial probe

Fig. 5 a stacked patch dual-polarized antenna [9].

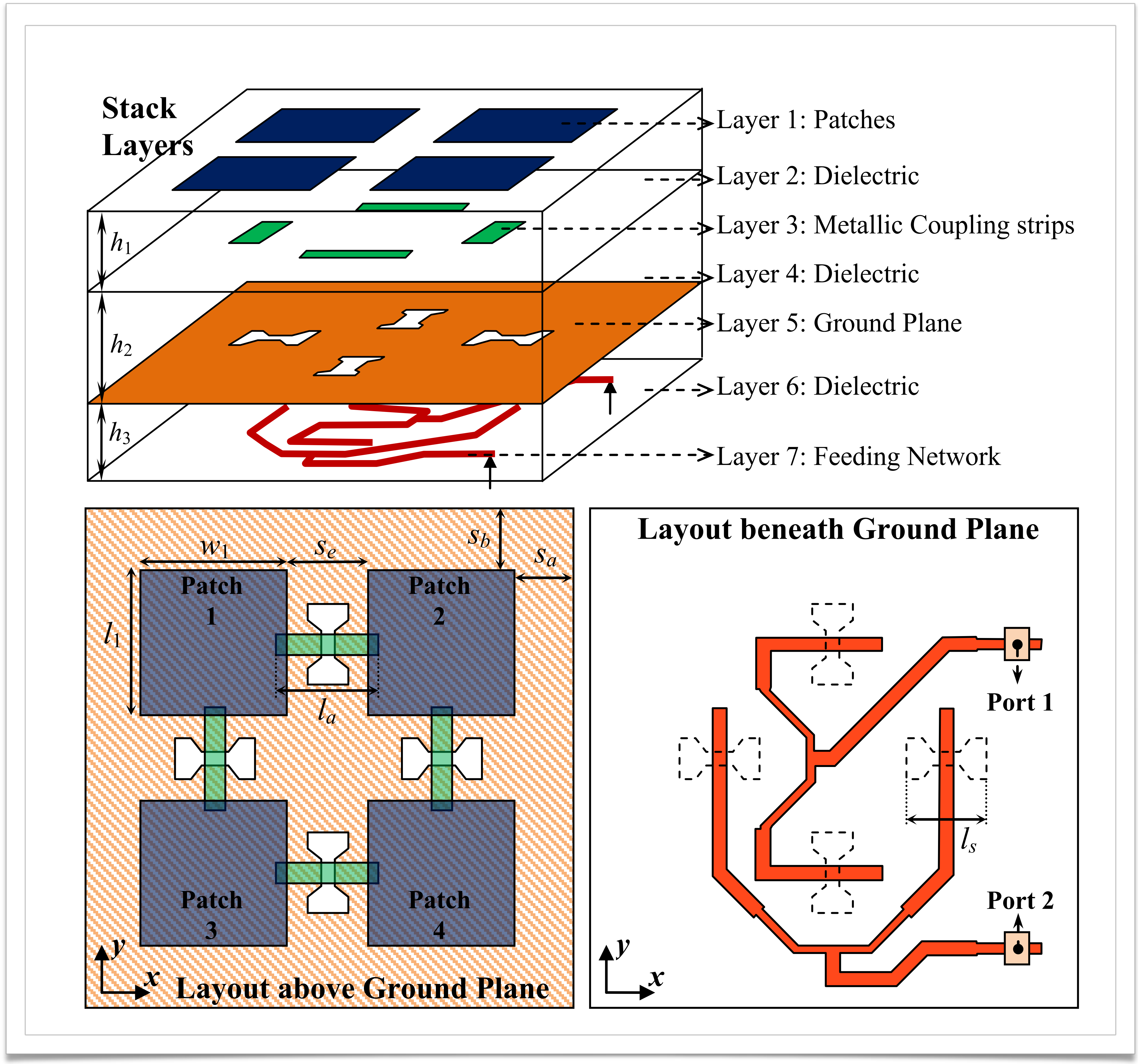
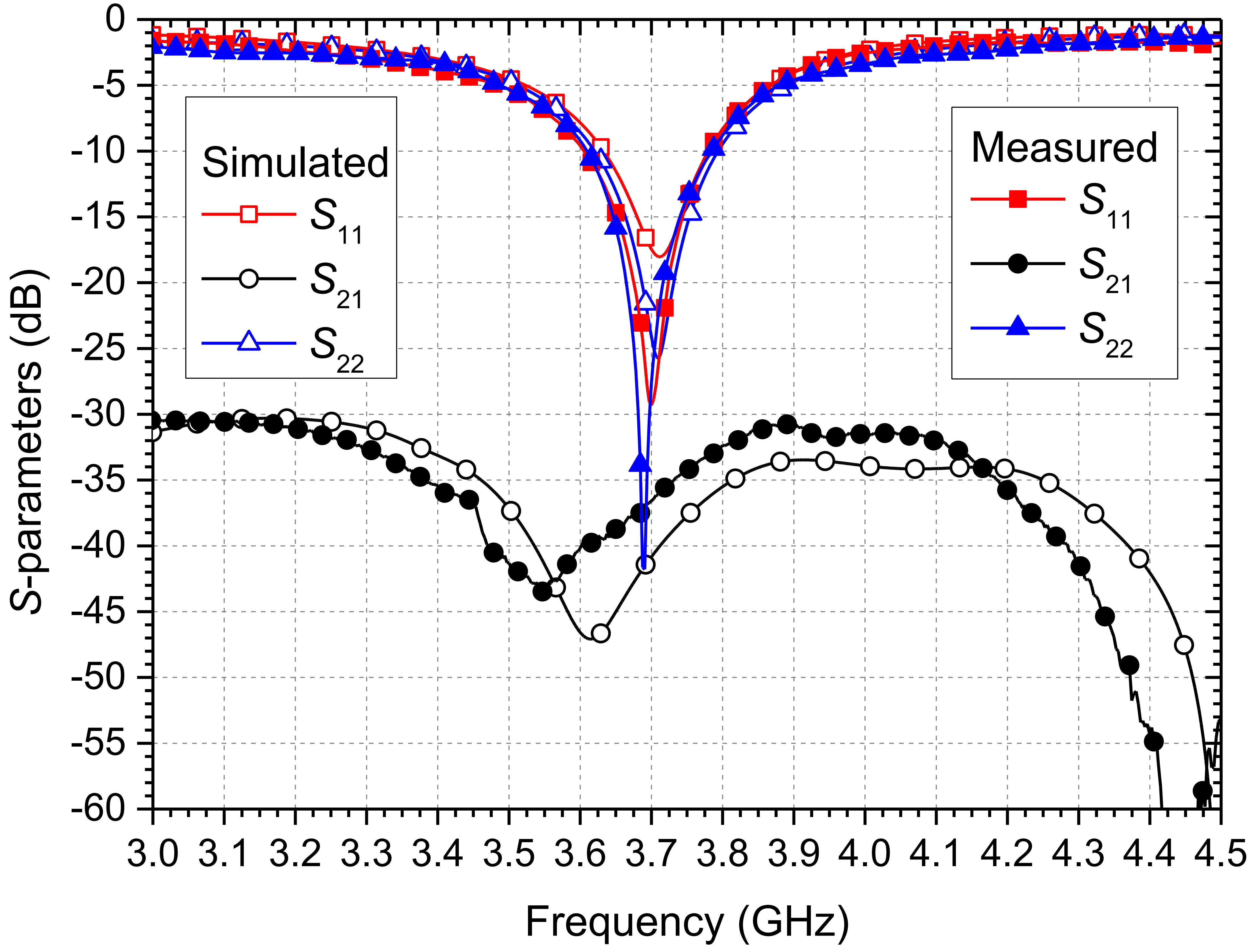
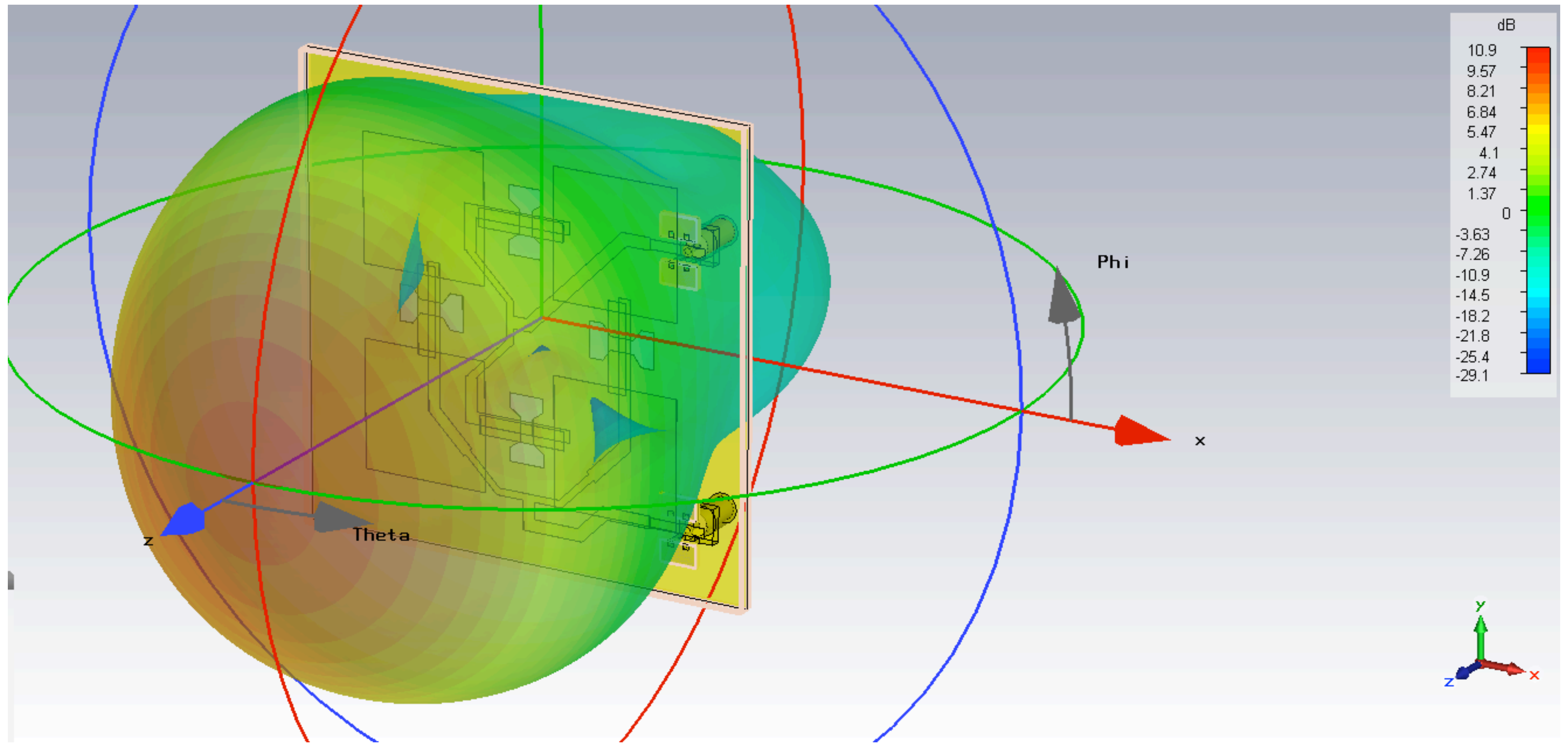

Stack Layers
h_1
h_2
h_3
Layer 1: Patches
Layer 2: Dielectric
Layer 3: Metallic Coupling strips
Layer 4: Dielectric
Layer 5: Ground Plane
Layer 6: Dielectric
Layer 7: Feeding Network
w_1
s_e
s_b
s_a
l_1
Patch 1
Patch 2
l_a
Patch 3
Patch 4
y
x
Layout above Ground Plane
Layout beneath Ground Plane
Port 1
l_s
Port 2
y
x

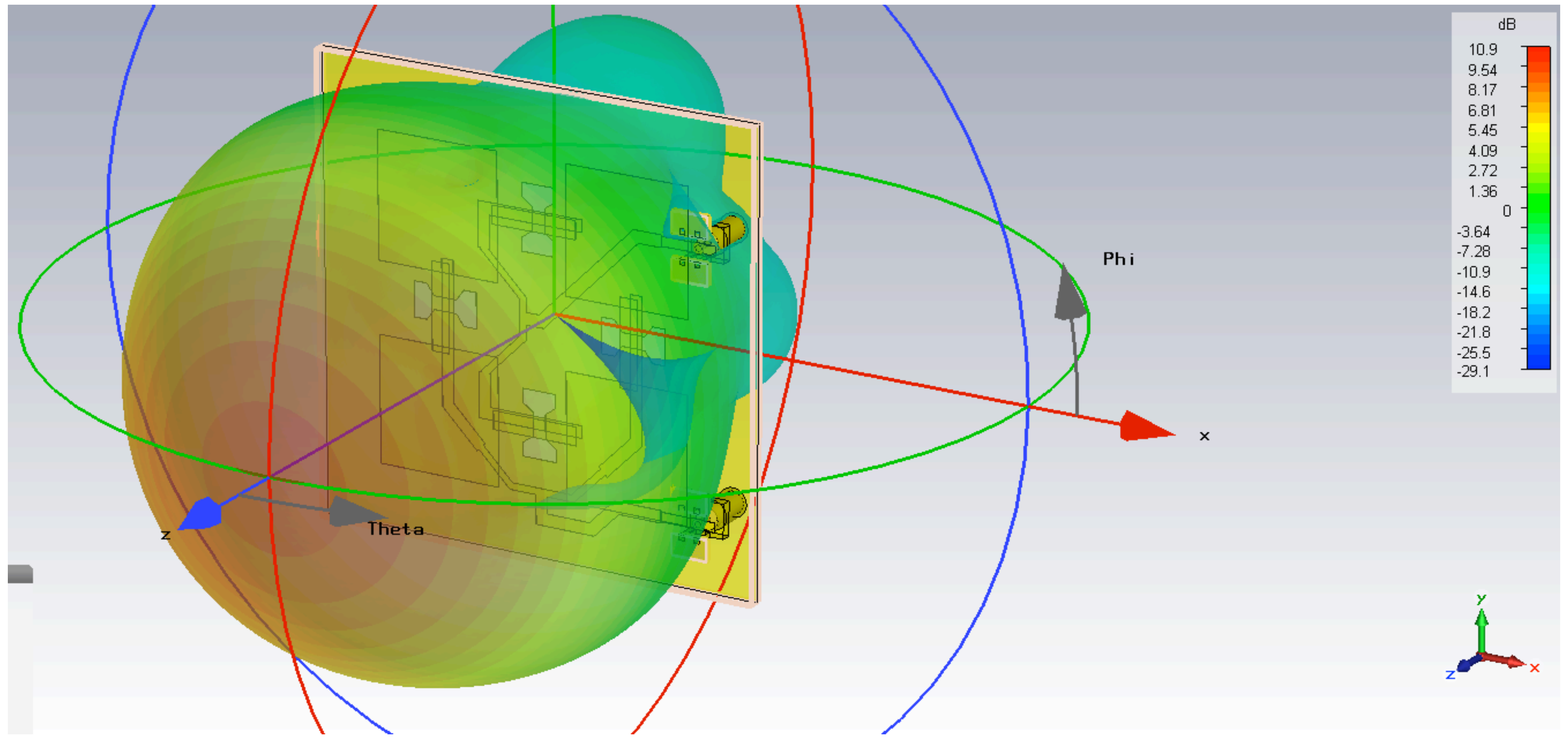
Fig. 6 the proposed single antenna for massive MIMO [2].

[9] O. Falade, M. Ur Rehman, Y. Gao, X. Chen, and C. Parini, “Single Feed Stacked Patch Circular Polarized Antenna for Triple Band GPS Receivers”, IEEE Trans. On Antennas and Propagation, vol. 60, no. 10, Oct. 2012.

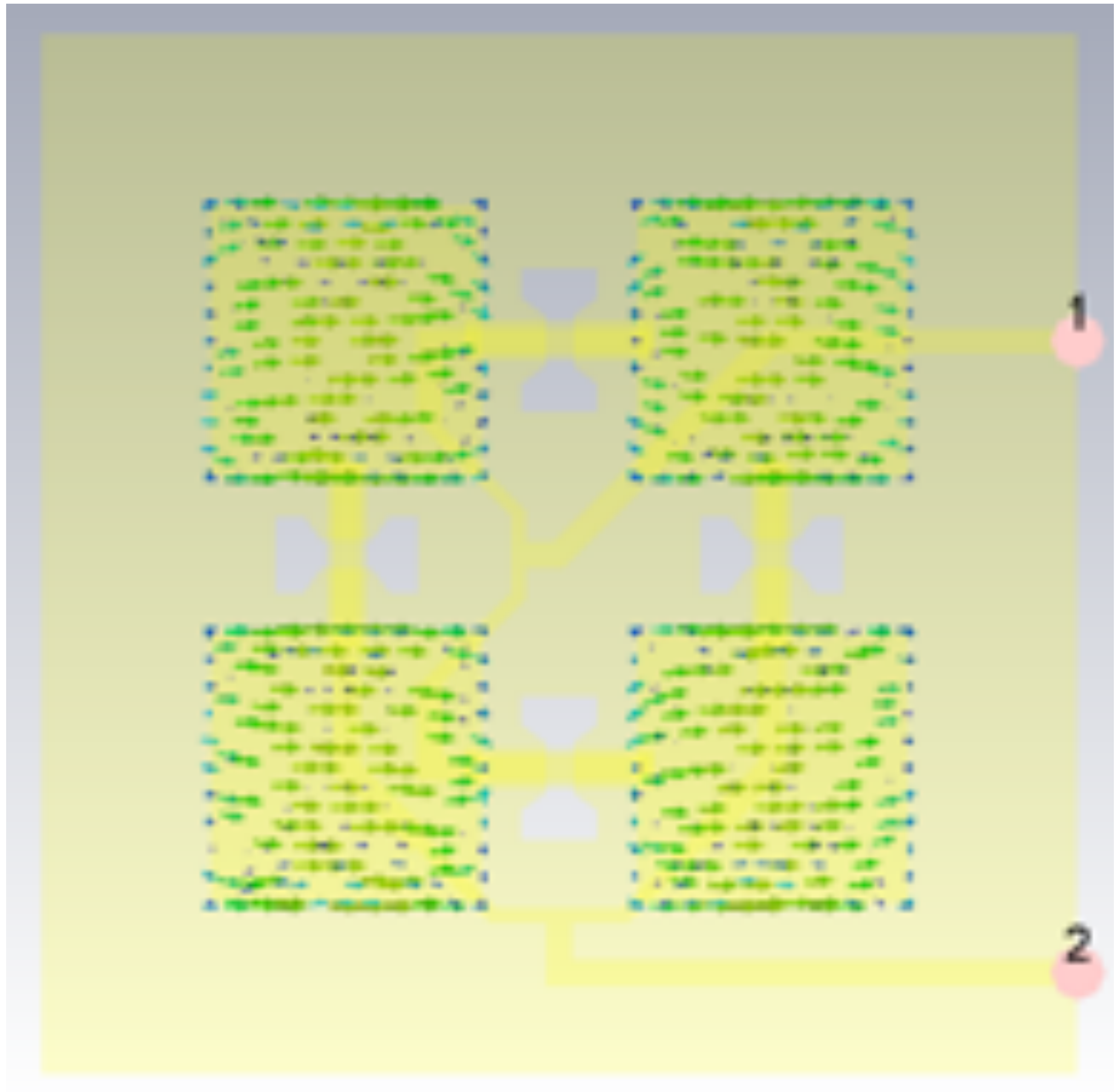
The performance of a single element



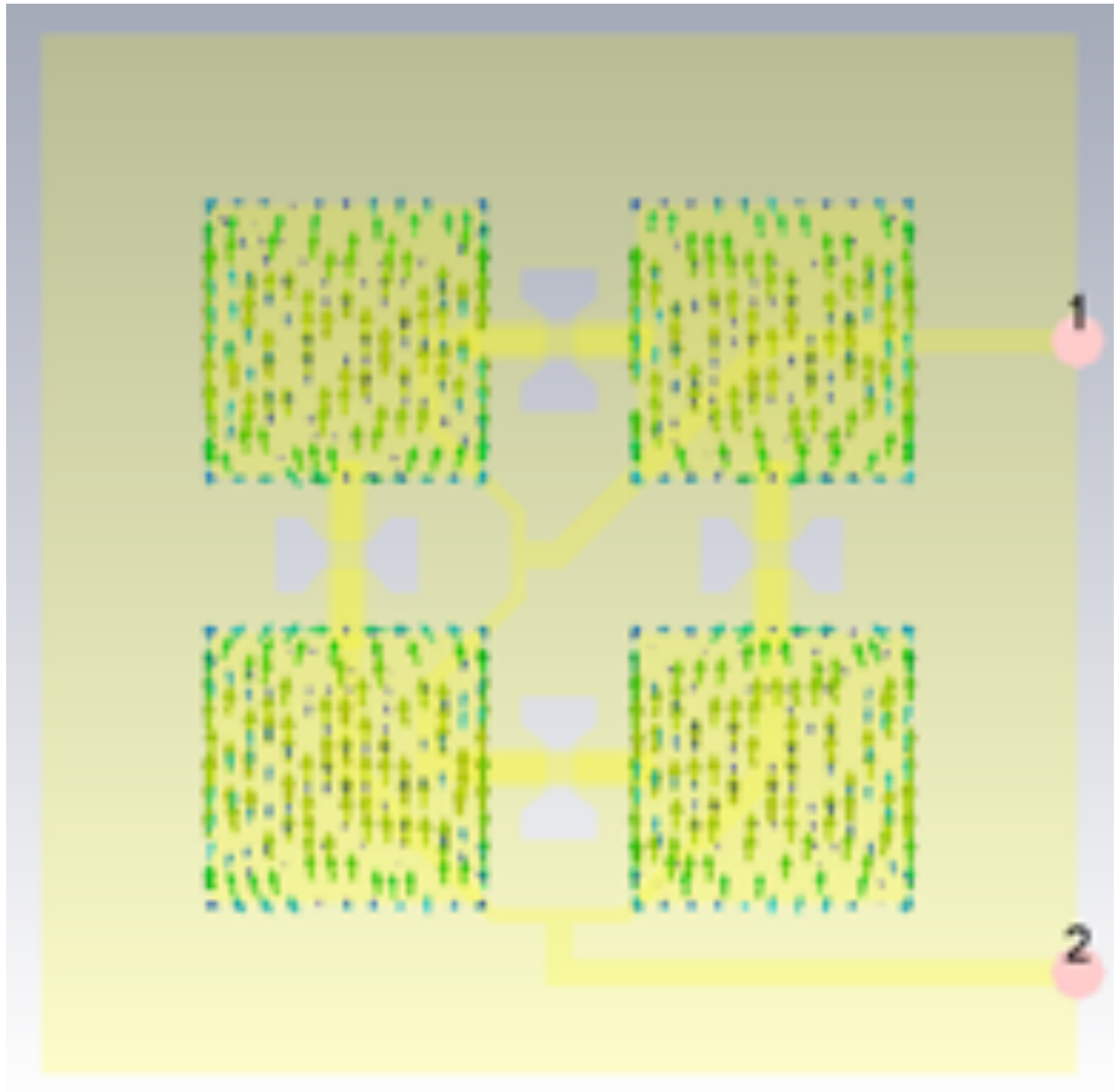

dB
10.9
9.57
8.21
6.84
5.47
4.1
2.74
1.37
0
-3.63
-7.26
-10.9
-14.5
-18.2
-21.8
-25.4
-29.1
Phi
Theta
x
y
z


dB
10.9
9.54
8.17
6.81
5.45
4.09
2.72
1.36
0
-3.64
-7.28
-10.9
-14.6
-18.2
-21.8
-25.5
-29.1
Phi
Theta
x
y
z

The current distribution of the single element

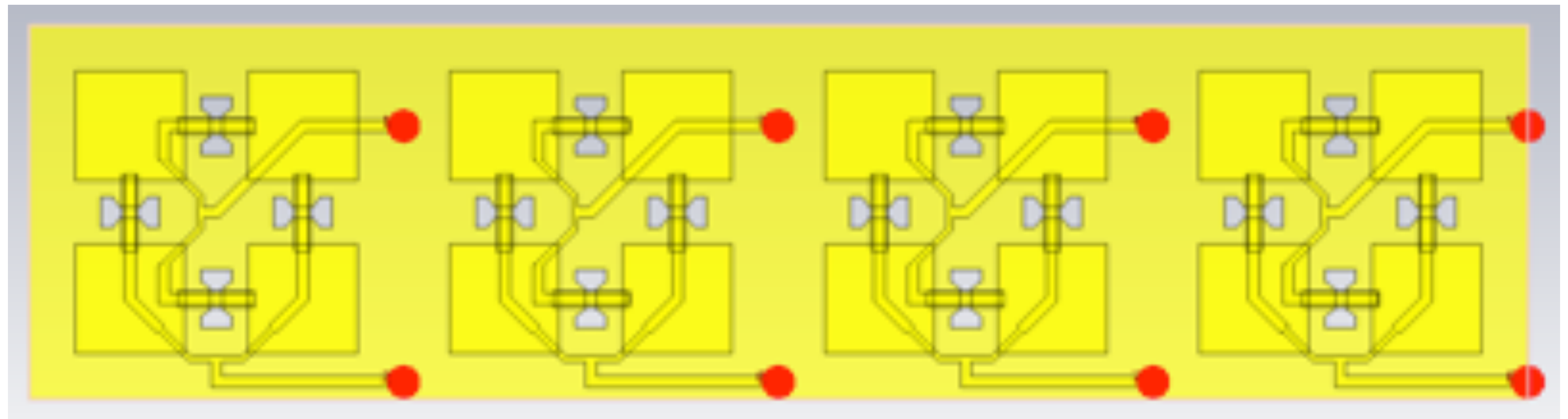


Port 1

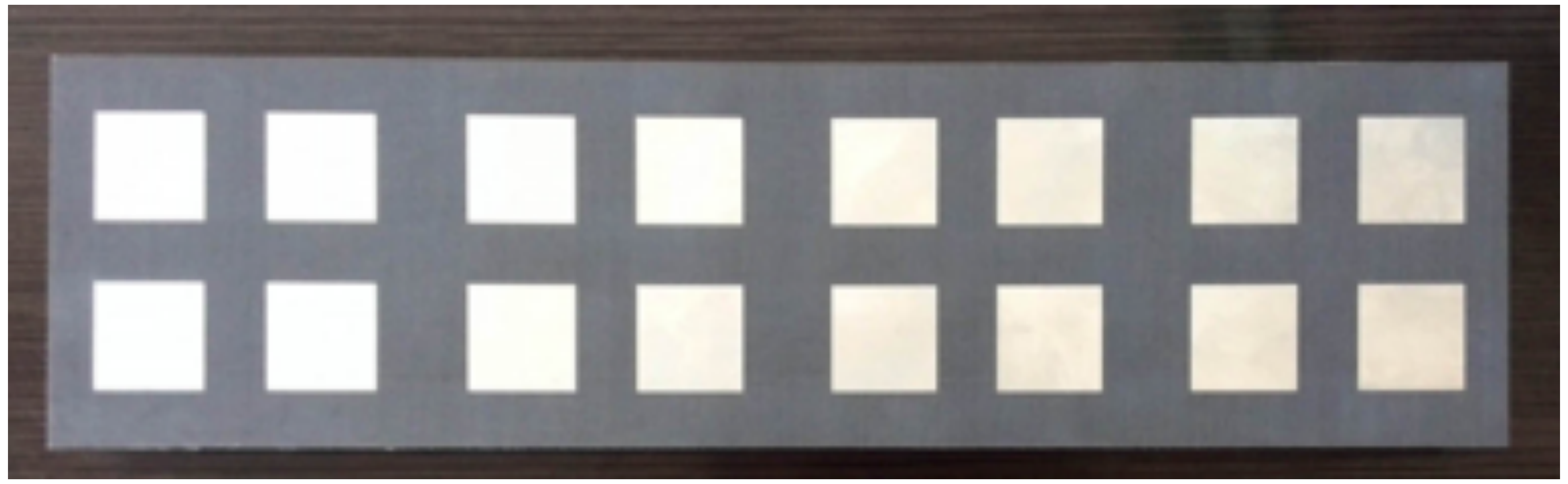


Port 2

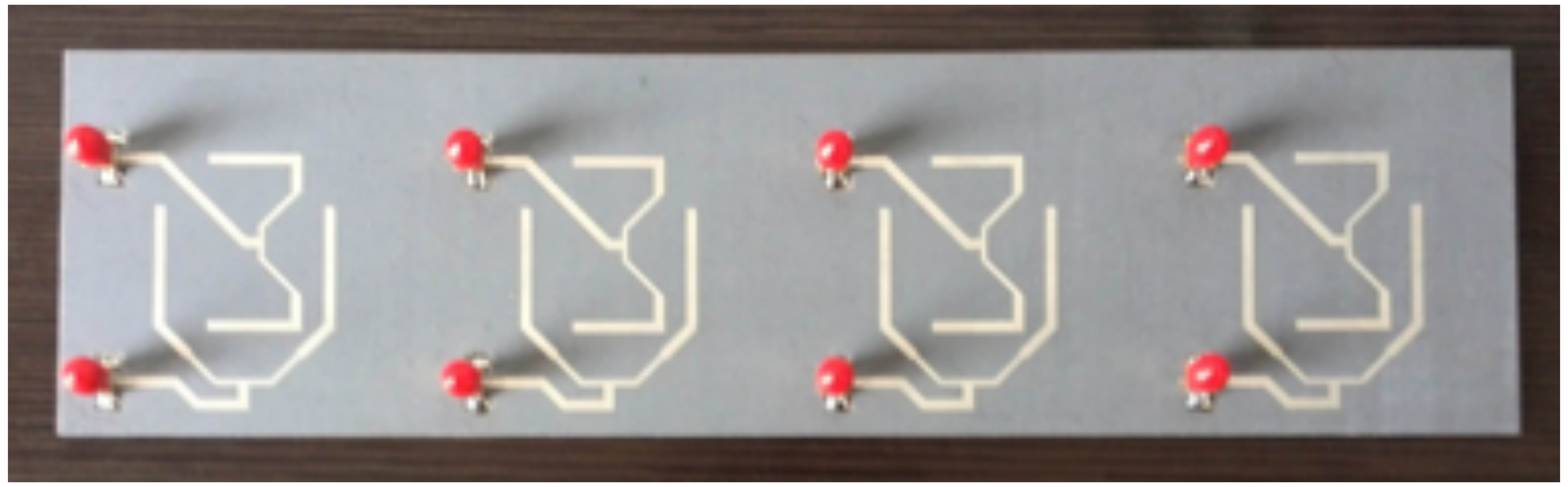
The design of a sub-array for Massive MIMO



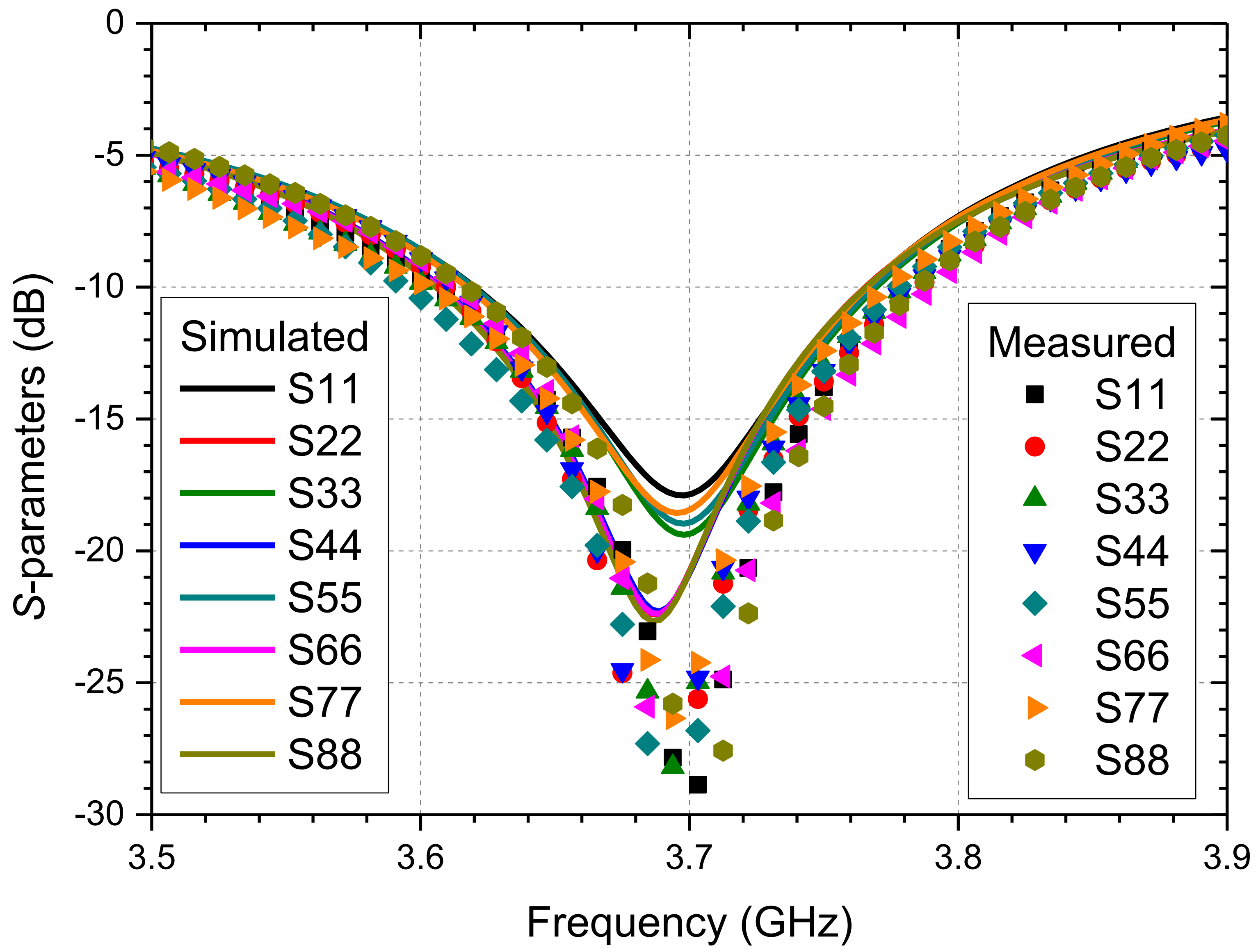
Simulated model

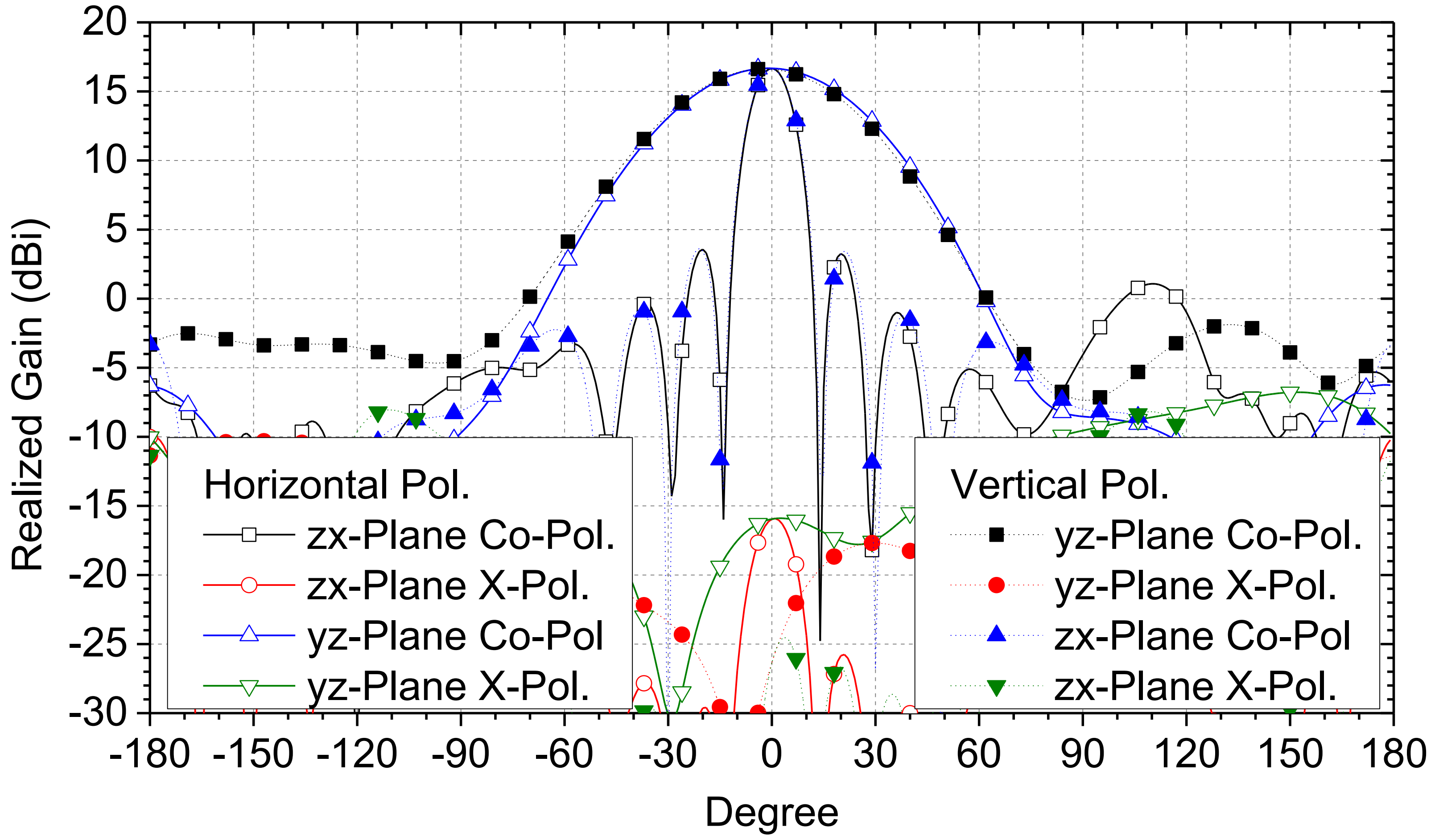


Top view of the prototype

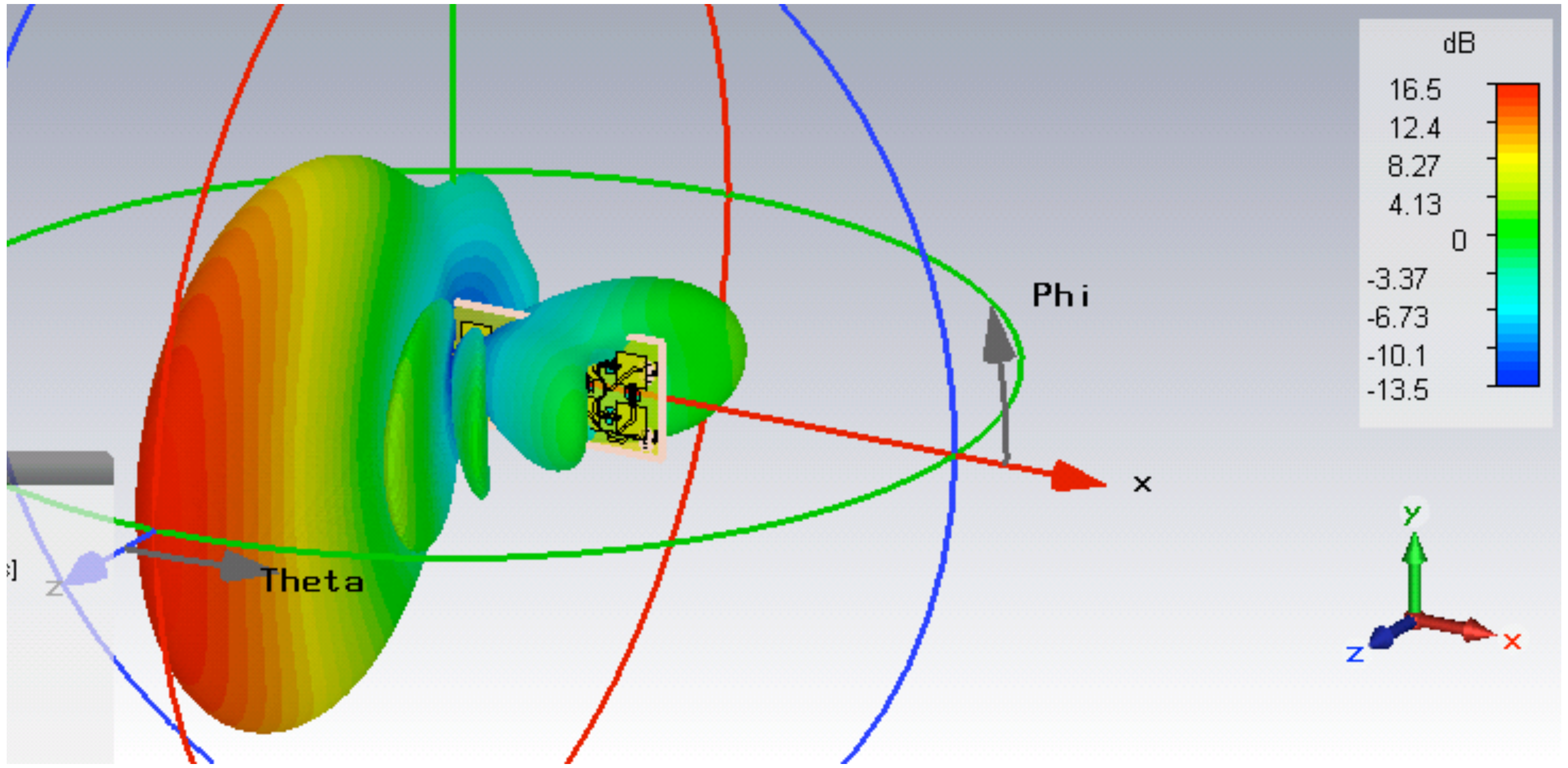


Bottom view of the prototype

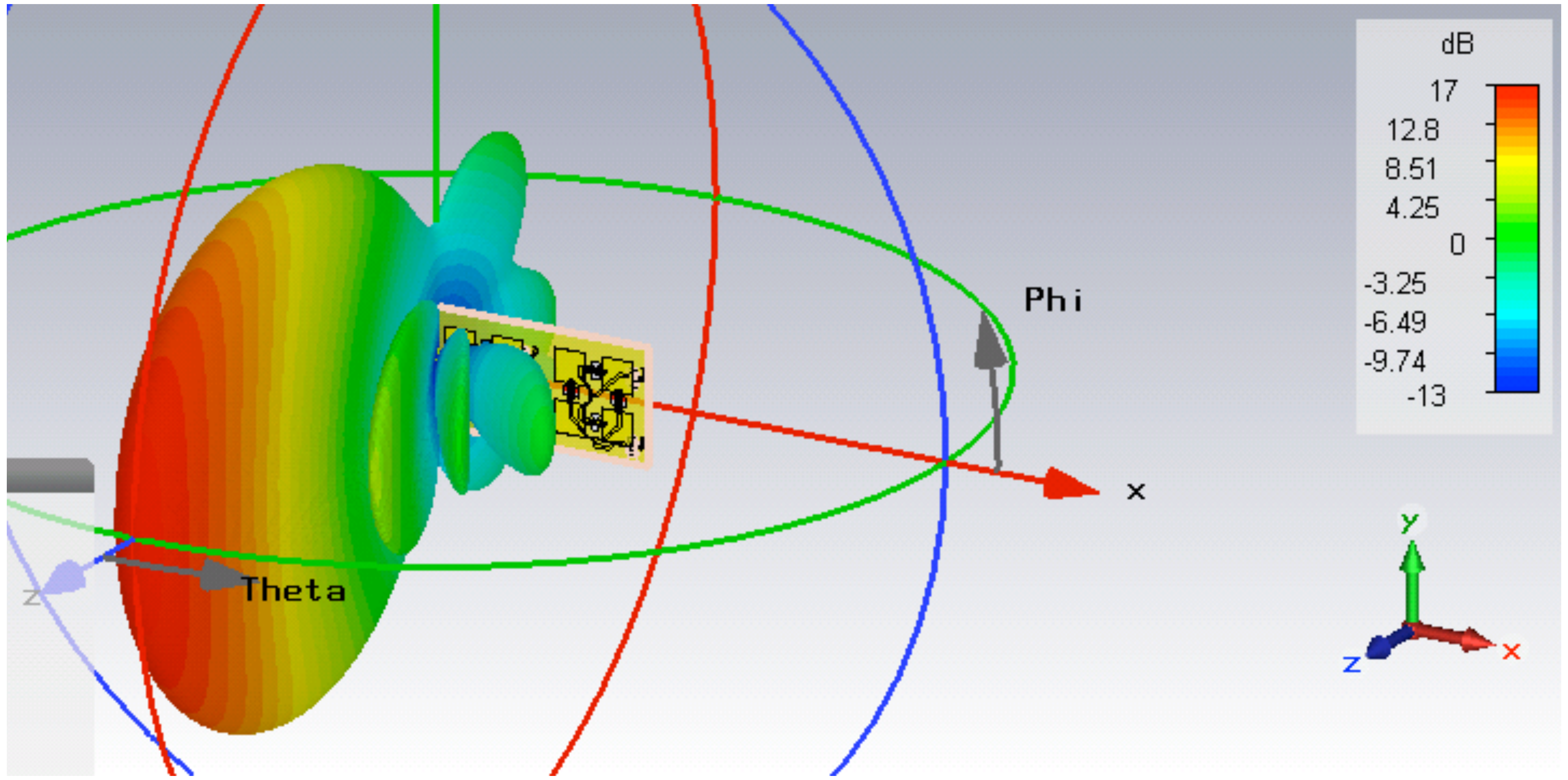




The performance of the sub-array for Massive MIMO

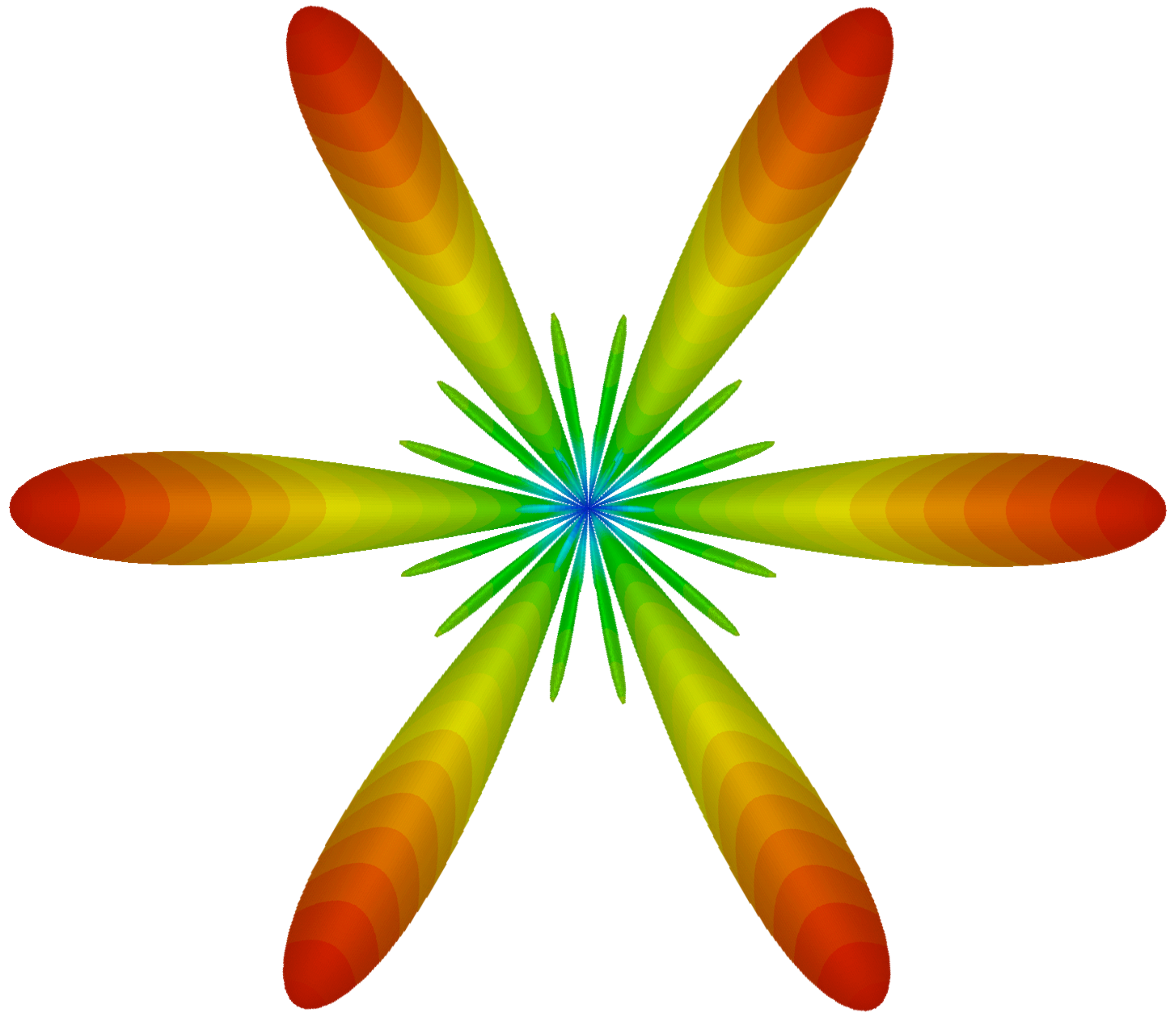

dB
16.5
12.4
8.27
4.13
0
-3.37
-6.73
-10.1
-13.5
Phi
Theta
x
y
z

Horizontal linear polarisation

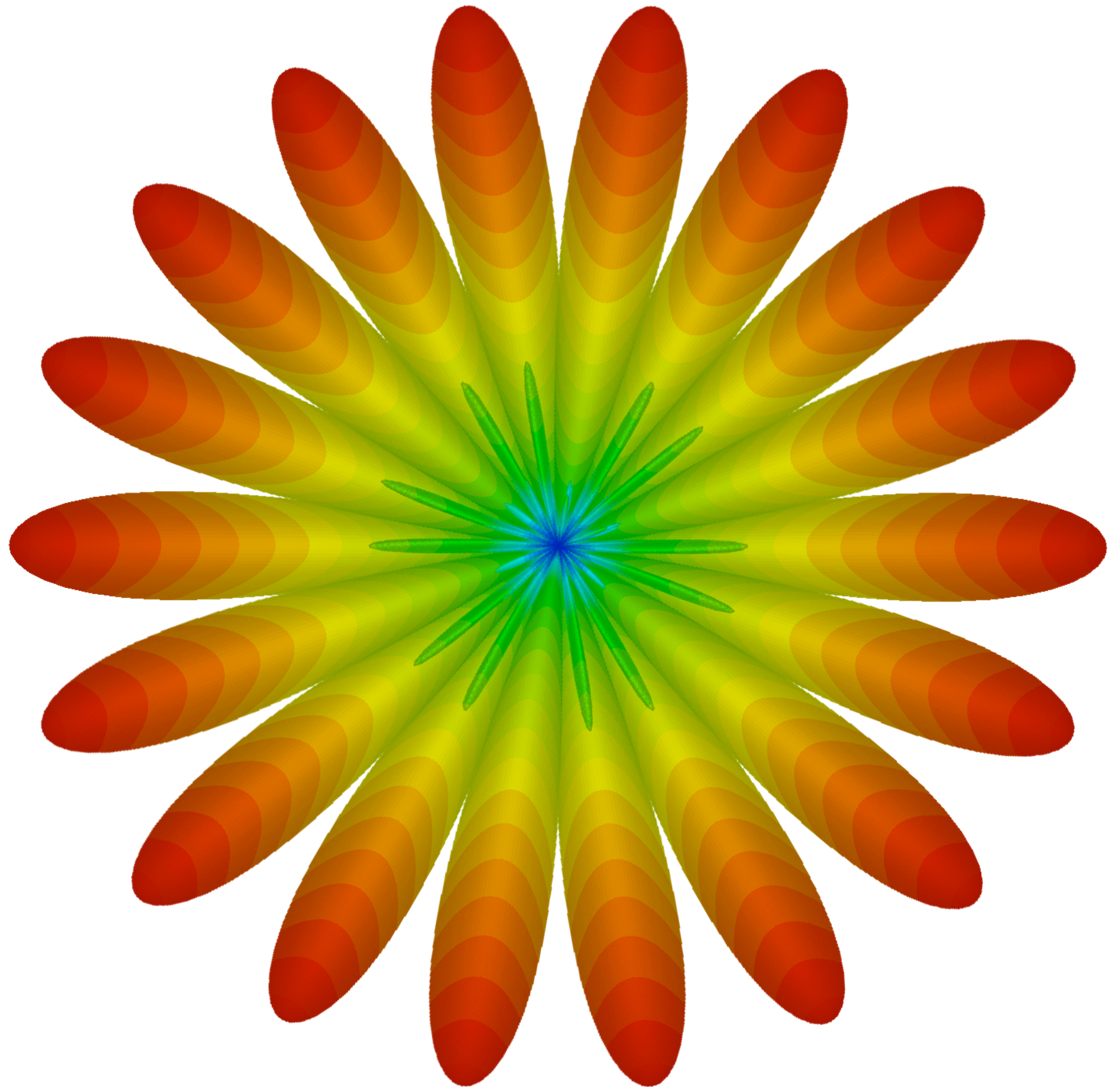

dB
17
12.8
8.51
4.25
0
-3.25
-6.49
-9.74
-13
Phi
Theta
x
y
z

Vertical linear polarisation

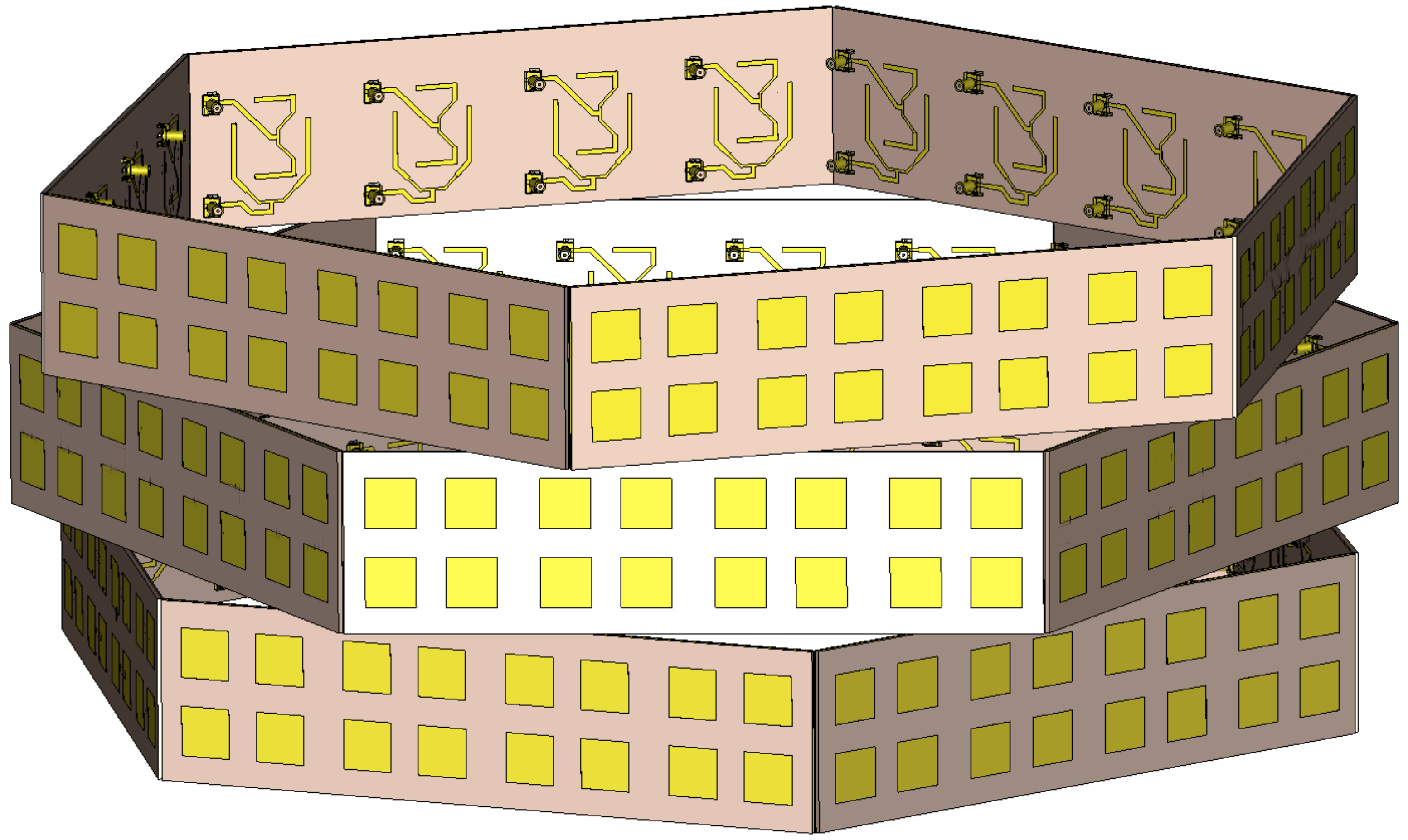
The design of a Massive MIMO antenna array



one hexagon



three hexagons stacked



The turning torso massive MIMO array

Conclusions & future work

- Recent progress on MIMO, MU-MIMO and massive MIMO has been reviewed with a proposed design, that is:
  - A compact dual-polarized antenna with four radiating square patches
  - A sub-array with the four proposed single element
  - A total 144 ports array with 18 sub-array for massive MIMO

- The features for the proposed massive MIMO antenna array:
  - Compact in size but also with low mutual coupling
  - The choice of higher gain narrow beam or lower gain wider beam
  - Flexible configuration and arrangement of the sub-arrays

There are enormous research challenges and opportunities for us to design and characterize over 100 antennas at the base station for Massive MIMO.

Questions, comments and suggestions are warmly welcome!

Dr Yue Gao
yue.gao@qmul.ac.uk

Acknowledgements:
Dr Rubo Ma
Prof Laurie Cuthbert
Prof Clive Parini

Queen Mary
University of London